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A Note on Non-Commutative Field Theory and Stability of Brane-Antibrane Systems

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ABSTRACT

It has been conjectured that a pair of $D5 - \overline{D5}$ branes wrapped on some non-trivial two cycle of a Calabi-Yau manifold becomes a stable BPS $D3$ brane in the presence of a very large B field and magnetic fluxes on their worldvolumes. We discuss this by considering the non-commutative field theory on the worldvolume of the pair of branes whose field multiplication is made with respect to two different $*$ products due to the presence of different F fields on the two branes. The tachyonic field becomes massless for a specific choice of the magnetic fluxes and it allows a trivial solution. Our discussion generalizes recent results concerning stability of brane-antibrane systems on Calabi-Yau spaces to the case of non-commutative branes.

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1. Introduction

In the last few years an important amount of work has been done for studying D branes at orbifold and conifold singularities [1,2] and their conformal limit within the AdS/CFT correspondence [3,4] as discussed in [5,6,7,8,9,10,11,12,13].

If we consider four dimensional field theories, they can appear either on $D3$ branes which are orthogonal to the singular space and carry integer charge or on (anti) $D5$ branes wrapped on different vanishing 2-cycles arising in the resolution of the singularity in which case the $D3$ branes are fractional branes and carry charges measured in terms of the B_{NSNS} fluxes on the resolution 2-cycles [14,15,16].

In this paper we will concentrate on the phenomena appearing on a pair of $D5 - \overline{D5}$ branes wrapped on S^2 cycles in the presence of a large B field and different fluxes on their worldvolumes. The two fractional branes have tension and charge proportional to B and $(1 - B)$, the constant being understood to arise from a world-volume magnetic flux that must be turned on in the antibrane and keeping the flux on the $D5$ brane equal to zero [16].

For general brane-antibrane pairs, there is a tachyon and the pairs are generically unstable [17]. The potential for the tachyon is an universal function with overall multiplicative factors coming from the brane tension [18]. For any nonzero value of the B -flux through the S^2 cycle, one may therefore naively expect to find a tachyon with its associated potential. However, we know from [19] that for a special choice of background B and F fields the tachyon becomes a massless scalar field and this implies that one should have a stable system. In the paper [16] it has been conjectured that this is an integer BPS $D3$ -brane. The problem is to explain the fate of the massless scalar which is not seen in the field theory on the integer lower $D3$ -brane. We are going to argue in the present paper that there is a trivial solution for the massless scalar field which actually therefore does not appear in the field theory on the brane-antibrane pair. The trivial solution will also determine the fact that the $U(1) \times U(1)$ gauge group survives.

The content of the present paper is as follows. In section 2 we will describe the non-commutative field theory on a $D5 - \overline{D5}$ pair wrapped on a vanishing S^2 cycle, in the presence of large B and different F fields on the worldvolumes of the pair components. We use the assumption of holomorphicity for the fields [20] to describe a trivial solution for the tachyon. This solution for the tachyon is different from the one of [21] where a B field is present but the magnetic fluxes on the branes are equal and from the one of reference

[20] where the magnetic fluxes are different but there is no B field and the field theory is commutative. We discuss a smooth transition between the two previous known solution, transition which necessarily passes through our solution.

The result is that the pair of $D5 - \overline{D5}$ cancel each other but what remains is an integer $D3$ brane instead of a tachyon condensation. One question that arises here is how could this happen in the view of the universality of the tachyon potential which tells us that the same phenomenon happens in any background. The answer is that the universality argument holds only for tachyons with zero momentum. In the case of different fluxes on the pair of $D5 - \overline{D5}$ branes, the tachyon are charged and they do not have zero momentum and the universality argument does not work. It would be very interesting to have a general description of this phenomenon.

In section 3 we discuss our results in connection with the results of [16] concerning the field theory on $D5 - \overline{D5}$ pair wrapped on the vanishing S^2 cycle at the apex of a conifold singularity, when we have a unit flux on the $\overline{D5}$.

2. Fluxes and Stability of $D5 - \overline{D5}$ wrapped on an S^2 cycle

Recently, important evidence has been accumulated showing that string field theory provides a direct approach to study string theory tachyons. The tachyons of unstable systems such as non-BPS D-branes or pair of brane-antibrane acquire an expectation value at a minimum of their potential where the total negative potential energies exactly cancel the tensions of the unstable systems [22,23,24,25]. These conjectures were checked by using approximation schemes in open string field theory and the accumulated evidence is impressive [18,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41]. In the framework of [42,43,21,44,45,46,47,48,49,50,51], the description of the tachyon condensation is much simpler when a large background B field is turned on. In our case a supplementary feature is that, besides the B field, we also turn on different fluxes on different branes. This will determine a different solution in our case for specific values of fluxes on pairs of branes and antibranes.

Consider the case when we have a flux F_1 on the worldvolume of the $D5$ brane and a flux F_2 on the worldvolume of the $\overline{D5}$ brane. Due to the presence of different gauge fields on the two branes together with the B field, the field theory on the worldvolumes of the

pair of branes becomes non-commutative and we have two different $*$ -products which are parametrised by [52]:

$$\theta_I^{ij} = \left(\frac{1}{F_I - B} \right) \epsilon^{ij} \equiv \theta_I, \quad I = 1, 2 \quad (2.1)$$

The field content of the theory is made of a $U(1)$ gauge boson $A_{1\mu}$ on the $D5$ brane, a $U(1)$ gauge boson $A_{2\mu}$ on the $\overline{D5}$ brane and a tachyon T which is charged under both $U(1)$ groups.

The effective theory is a $U(1) \times U(1)$ non-commutative gauge theory and the fields are multiplied by a noncommutative $*_I$ product with noncommutativity parameter θ^I , ($I = 1, 2$) given as above. The gauge field $A_{1\mu}$ is multiplied by $*_I$ product, the gauge field $A_{2\mu}$ is multiplied by $*_I$ product respectively. The complex tachyon $T = T_{12}$ together with its complex conjugate $\overline{T} = T_{21}$ being charged with respect to both gauge groups are also multiplied by using one of the $*_I$ products: namely, $T_{12} * T_{21}$ is defined by using $*_2$ while $T_{21} * T_{12}$ is defined by using $*_1$. For a $D5 - \overline{D5}$ system, the tachyon is a 2×2 matrix, the $*$ product appears as 2×2 matrix too and the $*$ products are applied to matrices. Because of the associativity of matrix products, it results that the $*$ product is associative and this is one of the required properties for any $*$ product.

A general discussion of field theories with different $*_I$ products would be very interesting and could reveal many important results but at this point let us concentrate on a $D5 - \overline{D5}$ system wrapped on a vanishing S^2 cycle. The fact that the cycle is a vanishing one determines a large value for the B and F field in order to obtain a finite flux, and this implies a large non-commutativity condition. Because there is no tachyon in the spectrum of the strings with both ends on the $D5$ brane or both ends on the $\overline{D5}$ brane but on the spectrum of the open strings which connect the pair, the tachyon is given by a 2×2 matrix

$$T = \begin{pmatrix} 0 & T \\ T^* & 0 \end{pmatrix} \quad (2.2)$$

i.e. $T_{12} = T, T_{21} = T^*$.

With B field and F fields on the world volumes of the pair of branes, the low-energy effective action is

$$S = \int_{S^2} \left[\frac{1}{4} \text{Tr} F_1^2 + \frac{1}{4} \text{Tr}_2 F_2^2 + DT * DT^* + V(T, T^*) \right]. \quad (2.3)$$

In the formula for the effective action the gauge field strenghts have the canonical form and the covariant derivatives are given by:

$$D_\mu T = \partial_\mu T + i(A_{1\mu} *_1 T - iT *_2 A_{2\mu}). \quad (2.4)$$

and

$$D_\mu T^* = \partial_\mu T^* + i(T^* *_1 A_{1\mu} - iA_{2\mu} *_2 T^*) . \quad (2.5)$$

The $V(T, T^*)$ is the form of the tachyonic potential and this can be extended as a polynomial around a fixed point:

$$V(T, T^*) = V(T_c, T_c^*) + 1/2 V''(T_c, T_c^*)(T *_2 T^* - T_c *_2 T_c^*) + \dots \quad (2.6)$$

where $V''(T_c, T_c^*) = m^2$ represents the mass of the open string tachyon. This mass depends on the values of B and F_i fields. Even without knowing a precise form for the dependence on the F_i fields, we can go directly to the particular case $\int_{S^2} F_1 = 0, \int_{S^2} F_2 = 1$ which corresponds to a zero flux on the $D5$ brane and a unit flux on the $\overline{D5}$ brane. As explained in [19,53], in this case the open string between the $D5 - \overline{D5}$ pair contains in its spectrum a massless scalar field instead of a tachyon, which was obtained by considering a projection on the open string Chan-Paton factors. In terms of the equation (2.6), this means that

$$V''(T_c, T_c) = 0 \quad (2.7)$$

In order to avoid any confusion, we still denote the scalar field by T even though is not a tachyon anymore but a massless scalar field.

Because we are on the limit of large non-commutativity due to the presence of large B and F fields, the equations of motion become:

$$[A_1^\nu, [A_{1\nu}, A_{1\mu}]] = A_{1\mu} *_1 T *_2 T^* - T *_2 A_{2\mu} *_2 T^* + T *_1 T^* *_1 A_{1\mu} - T *_2 A_{2\mu} *_2 T^*, \quad (2.8)$$

$$[A_2^\nu, [A_{2\nu}, A_{2\mu}]] = A_{2\mu} *_2 T^* *_1 T - T^* *_1 A_{1\mu} *_1 T + T^* *_1 T *_2 A_{2\mu} - T^* *_1 A_{1\mu} *_1 T, \quad (2.9)$$

$$-A_{1\mu} *_1 A^{1\mu} *_1 T + 2A_1^\mu *_1 T *_2 A_{2\mu} - T *_2 A_2^\mu *_2 A_{2\mu} = V'(T, T^*). \quad (2.10)$$

In [21], a solution has been given to these equations for the case of vanishing F_i fields. In our case we have non-vanishing and non-equal F_i fields so that solution is not valid for the new conditions described in the present paper.

In order to obtain a solution, we will use a generalization of the results of [20] to the case of non-commutative theories. The system of $D5 - \overline{D5}$ branes is a triple (E_1, E_2, T) where E_1, E_2 are $U(1)$ bundles over S^2 and the tachyon T is a map between them. In order to have a stable 3-brane the condition on the bundle charges is:

$$c_1(E_2) - c_1(E_1) = 1 \quad (2.11)$$

which is identical to the condition $\int_{S^2} F_1 = 0, \int_{S^2} F_2 = 1$ that we have in our paper. There is actually a minus sign difference between the equation (2.11) and the condition which appears in [20]. This is because the Chern-Simons terms contain terms like $B - F$ for the $D5$ brane and $-(B - F)$ for the $\overline{D5}$ brane, our $c_1(E_i)$ will be their $-c_1(E_i)$. Therefore our condition (2.11) is the same as the condition of stability of the $D5 - \overline{D5}$ pair. The equations of motion (2.8) - (2.10) are implied by the condition that all the fields be holomorphic meaning that :

$$F_{i,zz} = F_{i,\overline{z}\overline{z}} = D_{\overline{z}}T = 0 \quad (2.12)$$

The holomorphicity of T implies:

$$\overline{\partial}T + iA_{1,\overline{z}} *_1 T - iT *_2 A_{2\overline{z}} = 0 . \quad (2.13)$$

In the large non-commutativity limit, the derivative term can be neglected and the equation (2.13) becomes

$$A_{1,\overline{z}} *_1 T = T *_2 A_{2\overline{z}} . \quad (2.14)$$

The fact that E_1 is trivial means that A_1 can be gauged to zero at infinity and because E_2 has $c_1(E_2) = 1$ means that A_2 can be gauged to the form $A_2|_{\infty} = \partial\theta$ where $z = re^{i\theta}$. But equation (2.14) is valid everywhere which means that A_1, A_2 have the same behavior at infinity and this is contrary to the above choice for the asymptotic values at infinity. The only choice to satisfy equation (2.14) is to consider a solution for T as $T|_{\infty} = 0$.

In the case of zero B field, the solution found in [20] is of the form $T = f(r)e^{i\theta}$ with $f(0) = 0$ and $f(\infty)$ equal to a constant which is actually the mass of the tachyon. This is the solution of the vortex equations implied by the homophicity (2.12) and without neglecting the derivative terms. In our case, we do not change the condition $T|_0 = 0$ but the condition at ∞ is different, i.e. $T|_{\infty} = 0$. By changing the boundary condition at infinity we change the solution and we allow the system to have a trivial $T = 0$ solution everywhere. The change in the boundary condition at infinity can be also seen from the fact that in [20] the solution is $f(\infty) = \alpha$ where α is the mass of the tachyon and this becomes zero for our specific choice for the fluxes.

Our solution can be obtain by starting either with the solution of [21] and turning on different fluxes on the $D5 - \overline{D5}$ pair or starting with the solution of [20] and turning on a B field. The first solution is a Gaussian one which goes to zero at infinity and has a maximum

at the origin. In one turns now different values for the F fields on the pair, the system is not stable at the origin unless the tachyon solution becomes zero there so there is a factor $a(F_1, F_2)$ in front of the Gaussian solution which becomes zero for $\int_{S^2} F_1 = 0, \int_{S^2} F_2 = 1$. The second solution has a zero at the origin and has a non-zero value at infinity. If one turns now a B field, the value at zero is unchanged but the value at ∞ is changed due to the previous argument concerning the behavior and becomes zero for very large B field. Therefore we see that it is either the Gaussian solution which is deformed to a trivial one by turning on F fields or the vortex solution which is deformed to a trivial one by turning on B fields. We can navigate between the two non-trivial solutions by switching on and off the B field and the fluxes F_i .

We have thus argued that in the case of large non-commutativity, with a trivial E_1 bundle and with $c_1(E_2) = 1$, there is a trivial solution for the tachyon field $T = 0$. The discussion was based on the fact that we could neglect the derivative terms and the fact the tachyon field becomes massless for a specific choice for the values of the fluxes.

3. Fractional Branes and Conifolds

We will use the result of the previous section to discuss the conjecture stated in [16]. In the case of a conifold singularity, there is an apex where blowing up a vanishing S^2 cycle resolves the singularity. If we probe the singularity with $D3$ branes, we can study aspects of the 4 dimensional field theories on the worldvolumes of the $D3$ branes. There are two types of $D3$ branes in the theory, the integer (anti) $D3$ branes which are orthogonal to the singularity and fractional (anti) $D3$ branes which are (anti) $D5$ branes wrapped on the vanishing cycle [54,16,55,56,57].

The question is what happens when one wraps a $D5$ and an anti $D5$ on the vanishing 2-cycle. In the usual case, without fluxes, the $D5 - \overline{D5}$ system would just annihilate by the usual tachyon condensation according to the formula:

$$V(T_0) + 2M_{D5} = 0 \tag{3.1}$$

where T_0 is the expectation value for the tachyon. This is a general formula expected to be valid for $D5 - \overline{D5}$ pair on any background by using the universality argument. It is only valid for the case when the fluxes on the branes are equal and it is not expected to be valid for different fluxes as explained in the introduction.

In the present paper we are in the case of different magnetic fluxes. In [16], it has been stated that if besides the B field one turns on a unit magnetic flux on the $\overline{D5}$ brane and no magnetic flux on the $D5$ brane, the result is that one has stable BPS integer $D3$ brane instead of tachyon condensation. Their result was based on the fact that the correct gauge invariant quantity on a brane is $B_{NS} - F$ and that is what appears in the Chern-Simons terms. In [19,53] the result is that in the above specified condition, there is massless scalar in the spectrum of the open string connecting the $D5 - \overline{D5}$ pair and this is the tachyon whose mass has become zero due to the presence of the B fields and F_i fields. If we are to obtain an integer $D3$ brane, this field should not appear in the spectrum. But this is exactly what we have discussed in the previous section, i.e. the fact that the equation of motion (or the homomorphicity conditions) imply that it exists a trivial solution $T = 0$. Therefore our above results are in complete agreement with the expectations for the field theory on a integer $D3$ brane at a conifold singularity. The tension of the $D5 - \overline{D5}$ system wrapped on the vanishing S^2 cycle is recovered as the tension of the integer $D3$ brane.

To discuss the charge of the stable system one uses the form of the Chern-Simons term worked out in [58] and which can be extended to a non-commutative field theory in the lines of [59]. There are two terms in the Chern-Simons coupling, one involves the tachyon field and is given by

$$\int C \wedge d \text{Tr} (T \wedge D\overline{T}) . \quad (3.2)$$

and this is zero for our tachyon field solution. The second term arises from the coupling of the $D3$ brane RR potential to the relative $U(1)$ gauge field strength on the $D5 - \overline{D5}$ pair, i.e. $\int C_4 \wedge (F_2 - F_1)$. This means that in our case the induced $D3$ brane charge is one as expected. Our solution is different from the one of [21] where the first term in the Chern-Simons couplings contributed and the second was zero because $F_2 - F_1 = 0$ in their case.

What happens with the $U(1) \times U(1)$ gauge group which existed on the worldvolume of the initial $D5 - \overline{D5}$ pair? The DBI coupling

$$\int *F \wedge B = \int F^{ab} B_{ab} \quad (3.3)$$

tells us that the tachyon is charged under the relative gauge group $A_- = A_1 - A_2$ and is neutral under $A_+ = A_1 + A_2$, where $A_i, i = 1, 2$ are the gauge fields on the $D5$ and $\overline{D5}$ respectively. In the usual case when the tachyon condenses A_- becomes massive and therefore decouples from the low energy spectrum by Higgs mechanism. The tachyon field

plays the role of the Higgs field and the Higgs mechanism appears via tachyon condensation. The other gauge field A_+ , under which the tachyon is neutral, gets confined [23,60,61]. In our case the Higgs mechanism does not occur because the tachyon scalar field has a zero expectation value and therefore the combination of the gauge fields remains massless and is not removed from the low-energy spectrum. By using standard electric-magnetic duality as in [61], one can show that the second gauge group does not become confined so both gauge groups survive and this implies that the entire $U(1) \times U(1)$ gauge group survives. This is just the gauge group on an integer $D3$ brane at a conifold singularity. The theory on the $D3$ branes is a commutative one because there is no B or F fields along its worldvolume directions.

The above discussion tells us that a $D5 - \overline{D5}$ pair on a vanishing S^2 cycle with $F_1 = 0, F_2 = 1$ magnetic fluxes on the branes is a stable system and is an integer $D3$ brane.

In the presence of other $D3$ branes at the conifold singularity, the overall gauge group will be changed by a factor $U(1) \times U(1)$ which agrees with previous known results [7,16].

Our discussion can be easily extended for orbifolded conifolds to describe pairs of $D5 - \overline{D5}$ branes wrapped on different vanishing 2-cycles described in [57].

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